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Mechanical Behavior of Materials used for Paving in the Southwest of the Brazilian Amazon

Antônio C. R. Guimarães[a], Graziella P. Pires dos Santos[b*], Laura M. G. Motta[c]

[a b]*Fortification and Construction Section, IME, Rio de Janeiro 22290-270, Brazil*
[c]*Federal University of Rio de Janeiro COPPE, Rio de Janeiro, Brazil*

Abstract

This study presents geological aspects of the southwestern Brazilian Amazon and analyzes the geotechnical characteristics and mechanical behavior of lateritic gravel soils of this region in the country. The soils in this paper were divided into two groups: soils selected for the BR-429/RO project and a laterite deposit located in the Porto Velho city. Resilient modulus was determined by repeated load triaxial test for determination and evaluation of the total permanent deformation considering various stress states. In results of the tests was observed high resilient modulus values and low values of permanent deformation for all materials analyzed, a fact which corroborates the good mechanical behavior of materials used as road paving materials.

Keywords: Soil; laterite; paving; Amazon.

1. Introduction

The southwest Amazon region includes the states of Rondonia, Acre and part of the Amazonas state. It is a region of low road density, compared to the central-south, with few technical publications on pavement materials behavior which is used in that region. Thus, this study represents a small contribution to a better understanding of the stress-strain behavior of tropical lateritic soils used in construction.

In geology the term craton is used to identify large regions that did not suffered any orogenic recent processes such as folding, faulting and intrusions on a large scale. That is, some areas are

[*] Corresponding author. Tel.: +55 21 8056 7741; fax: +55 21 2546 7029.
E-mail address: graziellappires@yahoo.com.br

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susceptible to endogenous geological processes such as volcanic seismicity, and therefore are usually composed of very old rocks or so-called Brazilian crystalline basement. In Brazil there are at least two cratons, namely San Francisco and Amazon, where the state of Rondonia is located. The ancient rocks that make up the foundation occurred from deposits of various origins and ages, including the Quaternary alluvial deposits (up to 1.8 m).

According to the studies listed in the Geological Survey of Brazil, prepared by the Brazilian company of Mineral Resources (CPRM), the state of Rondonia is located west of the region known as the Tapajos Province, figure 1, according to subdivision developed by Almeida et al. (1977) apud Guimarães (2009), is also being named as a sub province of Madeira. The geotectonic framework of the southwestern Amazon craton, which is included in the state of Rondonia, and portraits of successive reactivations related to orogenic episodes as the pre-Cambrian was coming to an end. In the aforementioned publication, the CPRM authors propose that the identification of the regional object is as follows: extensive tectonic zone that involves a large segment of lithospheric deformation in the polycyclic stage, complex metamorphic relationships, significant granitized syn-tectonic magma and crustal reworking. These are products of evolution processes superimposed on the second course of one or more orogenic cycles. The cited work also proposed that the region should be called polycyclic orogenic Range Guapore and describes in detail the relevant aspects of its design in the lithostratigraphic column.

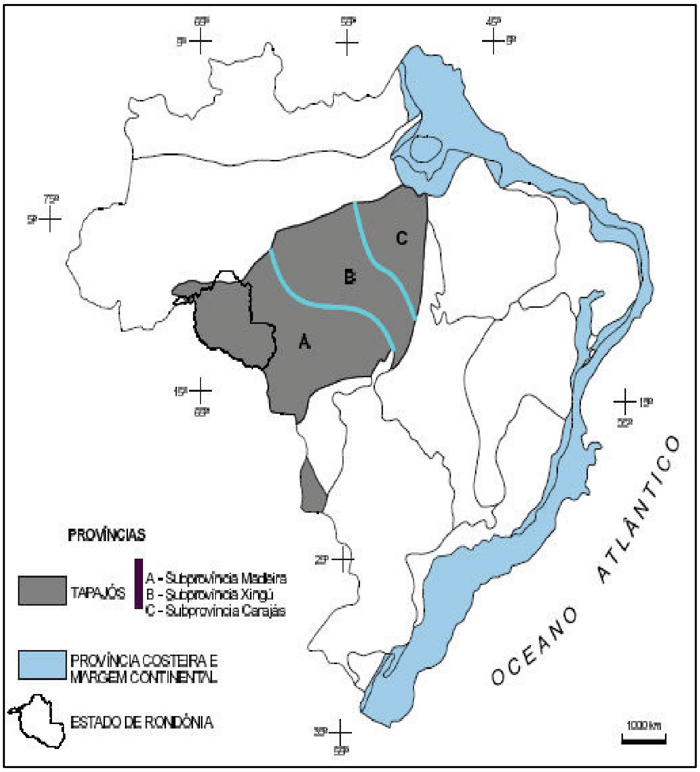

Figure 1: Structural provinces of Brazil and the State of Rondonia.
Modified from Amaral et al. (1977).

Figure 2 shows a fragment of Rondonia road map in which one can view part of the route of the BR-429, along which were collected from the samples of laterite used in this work.

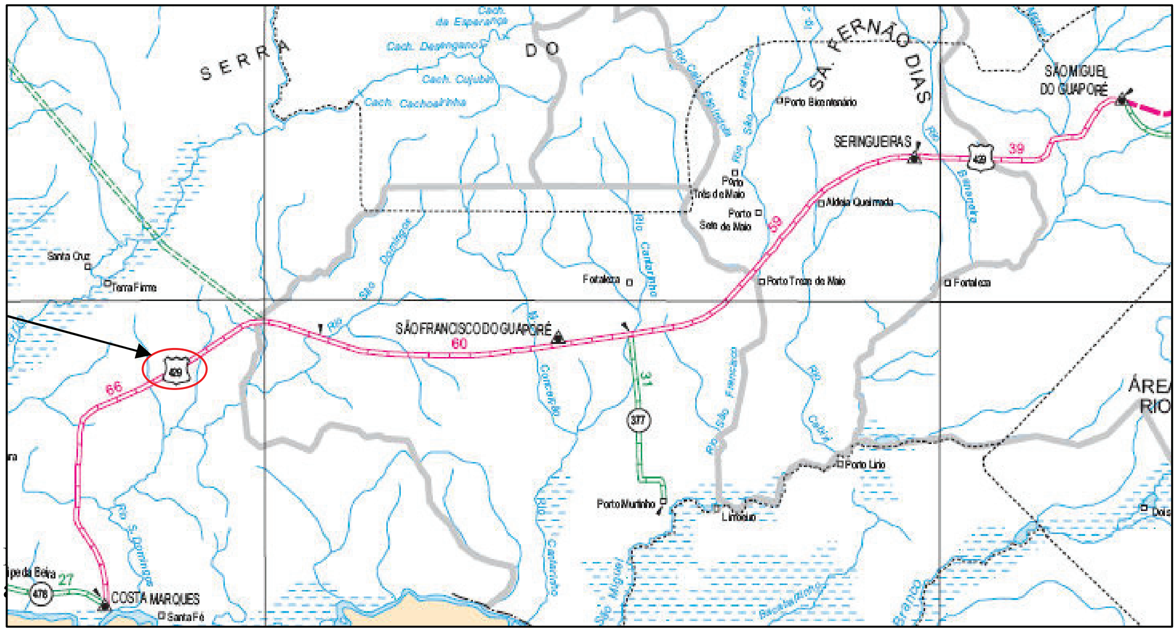

Figure 2: Road Map of Rondonia Including Part of Highway BR-429/RO.

2. OBJECT

With the aim of contributing to a better use of paving materials in the state of Rondonia was designed this study, which includes data from field and laboratory work obtained from a visit by one of the authors in that region of the country to paving of a highwayBR-429/RO lots. Thus, this study represents a small contribution to a better understanding of the stress-strain behavior of the tropical laterite soil used as background and sub-base for paving.

3. MATERIALS STUDIED

The various lateritic soils that make up the present study could not group into two sets of materials:

• Soils studied for the design of BR-429/RO

• Reservoir of "Coke" in Porto Velho

The soils for the preparation of road project BR-429/RO constitute a set of six deposits of laterite gravel base and sub-base, whose geotechnical characterization and resilient modulus values were used by Ferreira (2008), among many others materials for the preparation of a forecast study resilient modulus through neural networks. The data for the evaluation of permanent deformation were used to develop a model for predicting permanent deformation in soils (Guimarães, 2009). The materials were shown to be predominantly boulders, as seen in Figure 3, with 25% maximum percentage passing the N^{o} 200 sieve.

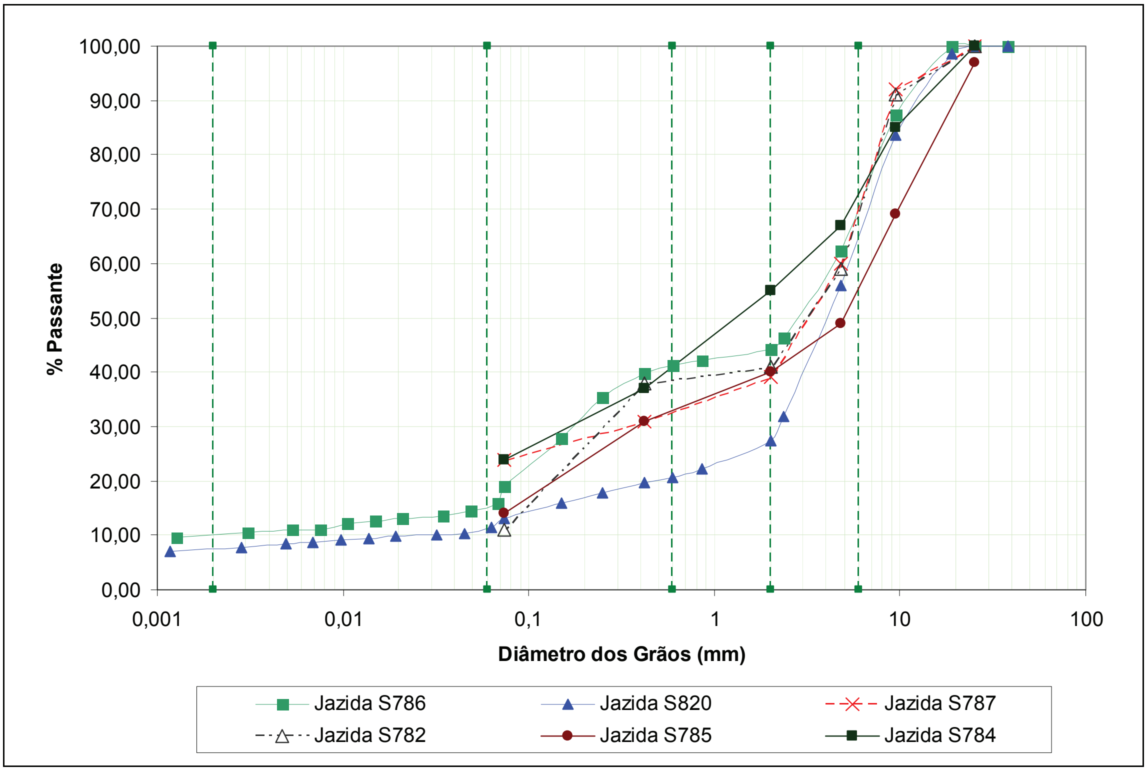

Figure 3: Granulometric composition of lateritic Rondonia studied.

The deposits of lateritic gravel or laterite, derived from the city of Porto Velho is located next to the factory company Coke in that city and has been exploited for urban paving, or as base layer, sub-base or primary coating. A common feature of the deposit is shown in figures 4 and 5, which can be observed in addition to the material aspect of boulders typical of dark red ferruginous laterites.

Figure 4: View of the Pool of Laterite Porto Velho/RO. Mineral deposit of "Coke".

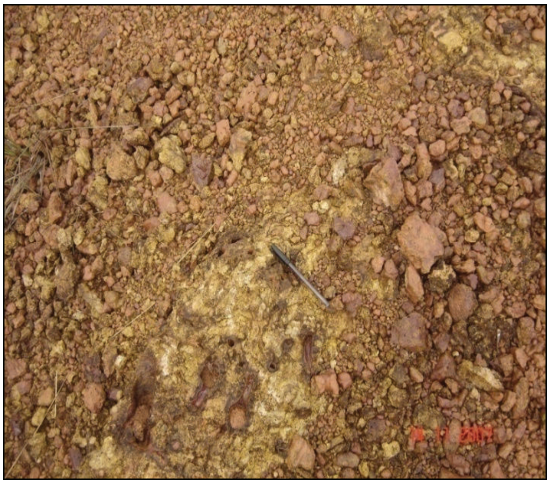
Figure 5: Boulder aspect of Porto Velho/RO. Mineral deposit.

The optimum moisture content of Laterite Porto Velho/RO was 12.6% and dry bulk density was 2.156 g/cm3.

4. METHODOLOGY

The methodology of laboratory tests conducted for this study varied according to the material analyzed. In the case of Porto Velho laterite, about one hundred kilograms of material was collected. Tests were performed at COPPE / UFRJ geotechnical laboratory, in order to determine geotechnical characterization, resilience module and permanent deformation considering several different stress levels.

Bodies of the test piece were molded into tri-parties cylinders, with 10 cm in diameter and 20 cm of height for the resilient module test and permanent deformation, and were adopted as these testing procedures developed at COPPE / UFRJ, as can be seen in Medina and Motta (2005) and Guimarães (2009).

For each test body cast during the compaction test was conducted the test resilient module, considering the addition of the following amounts of water: 400 ml, 450 ml, 480 ml and 500 ml. It was researched on the influence of moisture content on material resilient modulus value.
In case of materials used in the paving project BR-429/RO, a similar procedure was adopted, but different stress states were used for permanent deformation.

5.RESULTS

With laterite samples from Porto Velho was possible to perform a compression test combined with resilient modulus testing, data wich is presented in Table 1.

The amounts of water used and related accruals differ from the usual compaction test, because the main objective was to define more accurately the optimum moisture content. In addition, test body high humidity often has broken during the triaxial test, a fact which adds nothing to this research.

The optimum moisture content thus obtained was 12.6%, but even to moisture content of a percentage point lower than the optimal dry bulk density is very close to the optimal equivalent. Following are results of tests conducted with the materials collected.

Table 1: Test Data Compression with Laterite Held in Porto Velho / RO.

Test body	Water added (ml)	Humidity of Cp(%)	Dry density (g/cm^3)
CP 01	400	10.7	2.029
CP 02	450	11.7	2.105
CP 03	480	12.4	2.140
CP 04	500	12.6	2.156

5.1. Resilient Moduli Laterite of Porto Velho

Equation 1 represents the Resilient Modulus value of laterite Porto Velho obtained for test body of size 10 cm by 20 cm and packed with energy equivalent to the test proctor optimum moisture and intermediate compression.

$$MR = 203\sigma_3^{0,16}\,\sigma_d^{-0,32}\,MPa \qquad R^2 = 0,77 \tag{1}$$

where: MR: resilient module [MPa];
R^2: coefficient of correlation;
σ_d: deviation stress [MPa];
σ_3: confining stress [MPa].

Figures 6 to 13 are presented graphs of resilient module changes function of confining stress and deviation separately for each of the test body listed in Table 2.

The initial idea was to assess together the influence of moisture on the compression module resilient, but the low correlation coefficient obtained in most graphics prevents their curves are indeed representative of the behavior of the material. The reduction in resilient modulus values of the mixtures are related to the amount of water added to the mixture to the case of laterite from Porto Velho. The resilient modulus values indicated that the greater the addition of water in the mixture the lower the value of the resilient module for the deviation and confining stress.

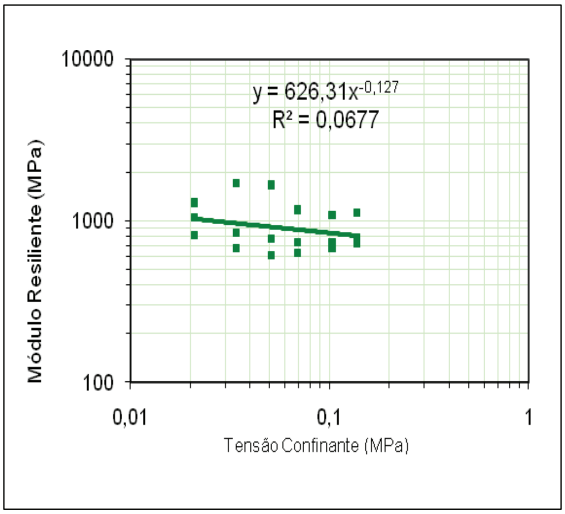

Figure 6: Variation of the resilient module with confining stress. Porto Velho laterite CP 1 (400 ml).

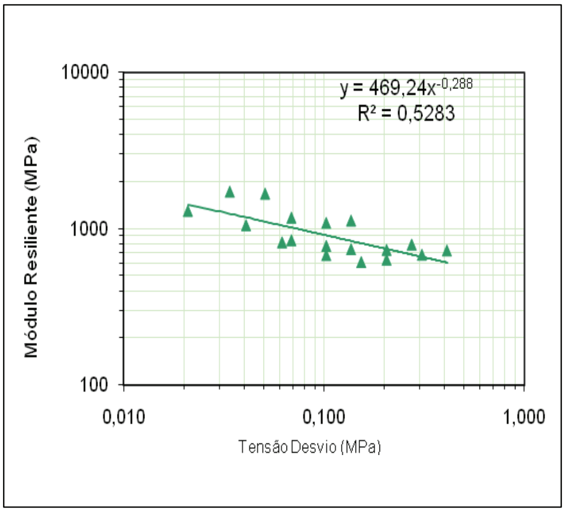

Figure 7: Variation of the resilient module with desviation stress. Porto Velho laterite CP 1 (400 ml).

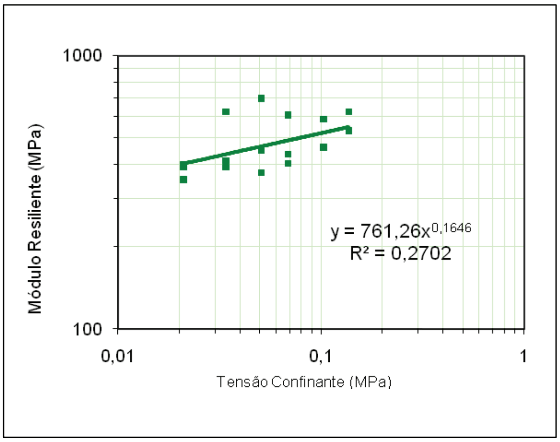

Figure 8: Variation of the resilient module with confining stress. Porto Velho laterite CP 2 (450 ml).

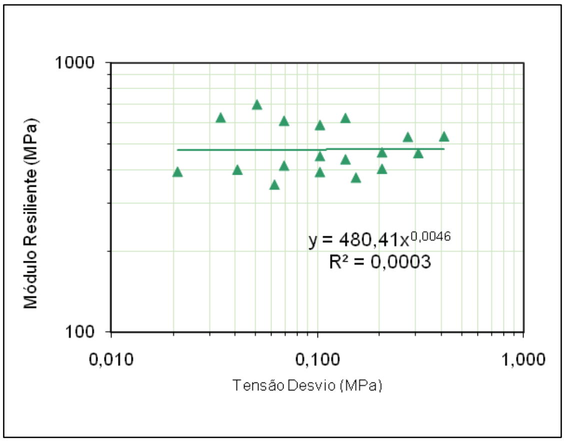

Figure 9: Variation of the resilient module with deviation stress. Porto Velho laterite CP 2 (450 ml).

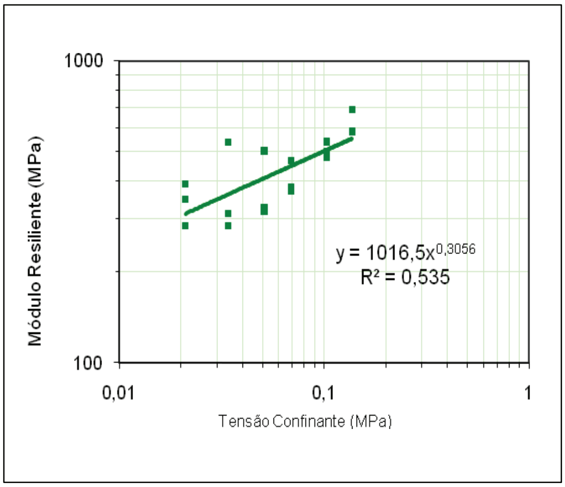

Figure 10: Variation of resilient module with confining stress. Porto Velho laterite CP 3 (480 ml).

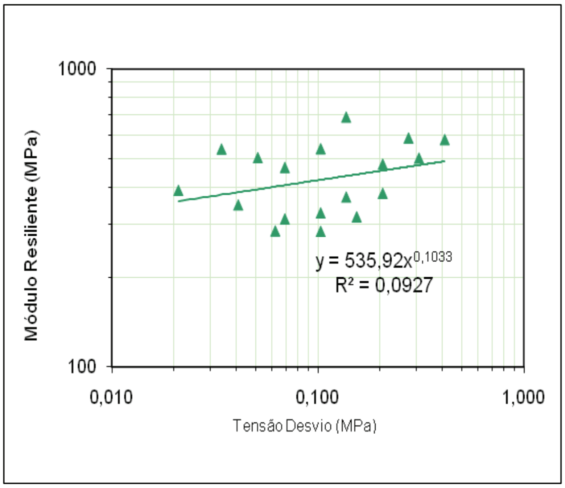

Figure 11: Variation of resilient module with deviation stress. Porto Velho laterite CP 3 (480 ml).

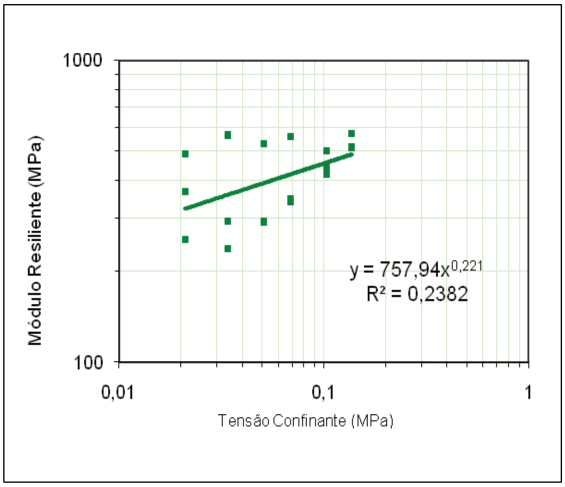

Figure 12: Variation of resilient module with confining stress. Porto Velho Laterite CP 4 (500 ml).

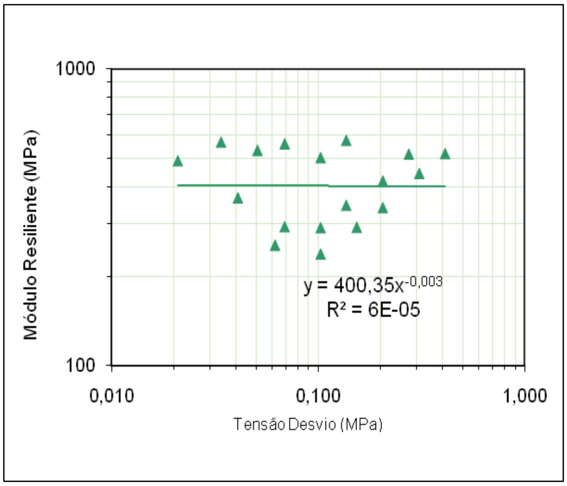

Figure 13: Variation of resilient module with deviation stress. Porto Velho Laterite CP 4 (500 ml).

For resilient moduli tests the brazilian standards adopt six stages of confining stress (21, 34, 51, 69, 103 and 137 kPa), and for each stage three stress deviations (σ_d) are taken such that the relation ($\sigma_{d/}\ \sigma_3$) can be 1, 2 and 3.

As seen in figures 6 to 13, in the case of test body with 400ml of water the magnitude of the average value of the resilient module was 1000 MPa, obtaining a better fit in the model representing the module which varies depending on resilient stress deviation. This test body however is presented with moisture below the optimum, which explains its high rigidity.

For the bodies of the test piece molded with 450 ml and 480 ml of magnitude of the average value of the resilient module was 400Mpa, since a better fit was obtained in the model of the moduli which varies depending on the confining stress. These resilient moduli values are consistent with those obtained for lateritic gravel in previous research, such as in Vertamatti (1988), Santos (1998) and Motta (1991).

In the case of test body molded with 500 ml of water there was a slight drop in the value of the resilient module and a better environment in the model as a function of confining stress.

5.2 Permanent Deformation of Porto Velho Laterite

Table 2 lists the permanent deformation tests which were performed with the Laterite of Porto Velho, the basic idea is to fix some reasons for different stress and off set stress. An attempt was made to use a stress conditions compatible with the tensions that can be obtained from the field, considering the standard wheel load.

Table 2: List of Permanent Deformation Tests Performed with Porto Velho laterite.

Test	Stress (kPa)		Stress	Reason	N	ε_π ($\mu\mu$)
	Desviation	Confining	σ_1 (kPa)	σ_1/σ_3		
1	400	100	500	5	156.000	1,225
2	200	200	400	2	214.000	1,289
3	160	80	240	3	180.576	0,382
4	280	140	420	3	417.000	0,828
5	360	180	540	3	180.000	1,166
7	300	100	400	4	336.000	0,721
8	160	40	200	5	153.000	0,768
9	240	60	300	5	250.000	0,542
10	125	25	150	6	250.000	0,413

The maximum total permanent deformation obtained was 1.289 mm in the case of test 2, conducted with stress deviation and equal to 200kPa confining stress. This value can be as low as 12mm since a common ground can be submitted by the end of life of a track wheel deepening. Thus, the laterite from Porto Velho showed a good behavior in relation to permanent deformation.

5.3 Permanent Deformation of the BR-429/RO laterites

The laterite samples of BR-429/RO were numbering as: S786, S820 and S787, and their respective values of compaction moisture and bulk dry density are presented in Table 3. The table shows also the state of tensions used in their triaxial tests of repeated loads taken for the assessment of the permanent deformation total samples, being used stress states compatible with the values of tensions usual the field for case of base layer and sub -base, considering the wheel load pattern 8tf.

Table 3: Values of moisture and compaction density in Apparent Dry BR-429/RO laterites.

Material	Test	Stress (kPa)		w_{cp} (%)	γ_s (g/cm^3)
		σ_d	σ_3		
S786	1	40	40	10,5	2,017
	2	120	40	11,5	1,953
	3	150	100	11,9	1,981
	4	250	100	10,8	2,015
	5	100	100	12,6	2,055
S820	1	40	40	12,9	1,927
	2	120	40	12,3	1,915
	3	150	100	13,1	1,883
	4	250	100	13,3	1,909
	5	420	100	13,7	1,929
S787	1	70	70	14,3	2,008
	2	70	70	13,1	2,027
	3	70	70	14,6	1,975
	4	70	70	14,4	1,922
	5	70	70	14,2	1,976

5.4 Evaluation of Total Permanent Deformation

The permanent change of strain over the cycles of load application is shown in Figures 14, 15 and 16, for deposits of laterites S786, S820 and S787, respectively. The curves have similar shapes, with very rapid growth to the initial 10,000 cycles, in general, and then tending to a constant value as the number of load applications increases.

In all trials the strong influence of stress state is evident, and in the case of laterite deposit of S786, Figure 14, the increased tension between the detour trials 3 and 4, ie, 150 kPa for σ_d = 250 kPa, represents an increase of the total permanent deformation of 0.471 mm to 0.930 mm, which corresponds to an increase of 102%.

For laterite deposit of S786, in a test conducted with a very low stress level ($\sigma_d = \sigma_3$ = 40 kPa) total permanent deformation of 0.189 mm was observed after 156,000 cycles of load application. In the second trial confining stress remained the same but the stress σd was increased three times increasing the total permanent deformation of 0.452 mm, ie, an increase of 139%.

For the laterite deposit S786, tests 2 and 3 were conducted with a very close stress level and very different confining stress, σ_3 = 40 kPa in test 2 and σ_3 = 100 kPa in test 3. It is observed that the curves representing the permanent deformations are very similar, almost overlapping, indicating that the confining stress has little influence on the total permanent deformation of the material to the universal confining stress range adopted. This trend was also observed in laterite deposits of S787 and 820.

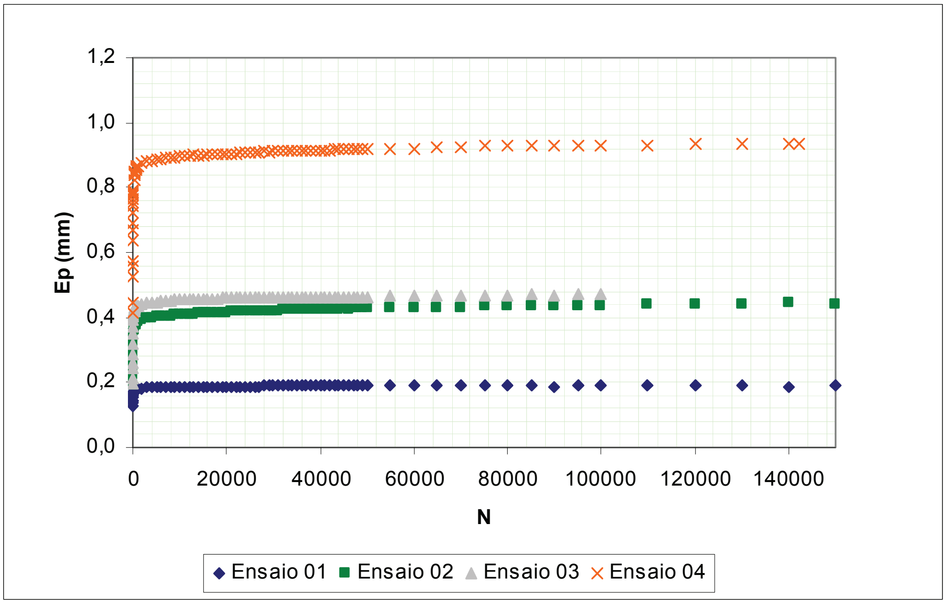

Figure 14: Variation of the total permanent deformation to the laterite reservoir S786.

In the case of laterite deposit S820, the variation of the total permanent deformation is shown in Figure 15. It was possible to perform one more test than for the S786 deposit. This was the 5th test, conducted with tension σ_d = 420 kPa confining stress σ_3 = 100 kPa, A total permanent deformation of 2.843 mm was observed with 160,000 cycles of load application. In this case it should be emphasized that the test stress is quite high compared to the 560 kPa stress induced by a standard load of 8.2 tf on top of a coating of any surface.

That is, in a real situation the asphalt coating would be subjected to a stress level closer to 560 kPa, whereas the bottom layer or sub-base would have lower stress corresponding to lower stress usually used in test.

With a direct application of the results, we see that the fifth test indicates a contribution of the base layer of laterite in the order of 2.843 mm for the total collapse of the track-to-wheel, whose value can be considered as permissible 12.5 mm. That is, even in disadvantageous conditions the material shows good resistance to permanent deformation, a moisture condition for optimal compression and compaction energy equivalent to the intermediary proctor test.

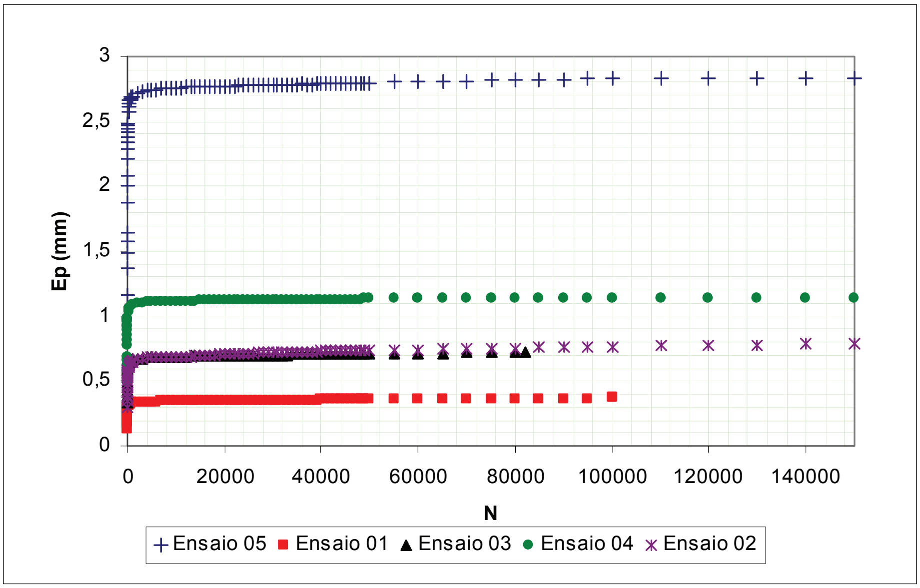

Figure 15: Total for the Permanent Deformation of laterite quarry S820.

In the case of laterite deposit S787, Figure 16, the tests were intended to investigate the influence of moisture on the compaction or total permanent deformation of the material, with all tests conducted with the same state of tension ($\sigma_d = \sigma_3 = 70$ kPa).

The second test, shown in Figure 16, corresponds to the material compacted at optimum moisture content and showed total permanent deformation of 0.437 mm to 100,000 cycles of load application, thus very low. The moisture changes made were very small, mainly because it was not possible to shape other test body with higher humidities.

Analyzing Figure 16 we can observe that the curves obtained tend to be parallel to each other, as it increases the number of load application. In addition, the total permanent deformation increased with increasing compression of the humidity of the test body, although not directly proportional. With absolute humidity of compression ranging from 13.1%, 14.3%, 14.6% and 15.6% had total permanent deformation of 0.437 mm, 1.992 mm, 3.298 mm and 3.427 mm, respectively.

In these trials, unlike the others, the condition for total permanent deformation of moisture above the compression reached great values that can be considered as high, the test cases 3 and 4.

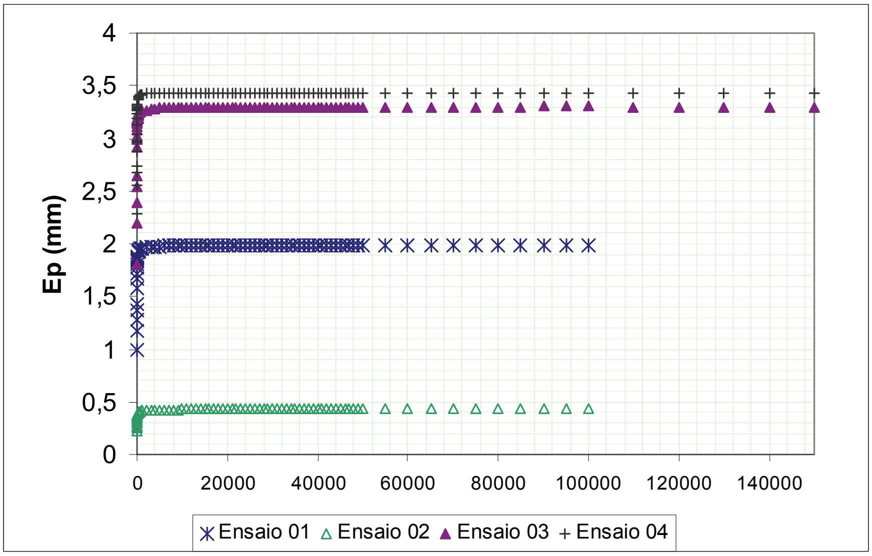

Figure 16: Total for the Permanent Deformation of laterite quarry S787.

6.Conclusion

Tests of various lateritic gravels of the southwestern Amazon show high resilient moduli values and low values of permanent deformation. This fact confirms the high mechanical performance of these materials when used as road paving materials.

The results show that the resilient module of Porto Velho achives ranges between 350 and 600MPa, for various stress states considered and for moisture content, close to optimal. These values can be considered high and consistent with values obtained for similar soils, confirming once again the suitable mechanical behavior of this material.

The permanent deformation curves of laterites BR-429/RO show a high rate of increase until a critical value is reached, with no further increase despite more application of load. Therefore, these materials show a suitable performance considering this criterion. The exception observed was the case of laterite deposit S787, which reached a value of permanent deformation of up to 3.5 mm - with moisture content of the soil - which can be considered high. However, the moisture used was higher than optimal, and the permanent deformation curve also showed the same behavior of high initial growth, when no increase despite further application of load. As a matter of fact, it has a favorable performance suitable as a paving material.

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